# OPERATION OF A TRIGGERED VACUUM FLASHOVER SWITCH ON PAWN


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## Abstract

Pawn is a prototype inductive storage pulsed power generator with two switching stages. The first stage is a wire fuse array driven by a low voltage (≈40 kV) capacitor bank, and the second stage is a fast opening vacuum switch such as a plasma erosion opening switch. A triggered vacuum flashover switch isolates the fuse stage from the second stage during fuse conduction. The switch consists of an insulating ring sandwiched between electrodes. Ultraviolet light and plasma from small spark discharges initiate a flashover of the insulator surface to close the switch. The trigger command is sent by fiber optic link.

The switch can be command triggered after holding off voltages for ≈15 μs; peak holdoff voltage is ≈85 kV. The time to closure decreases from 240 ns at a closing voltage of 15 kV to 140 ns at 50 kv with a typical jitter of ±50 ns. Typical fuse stage output current is ≈1 MA with an average risetime of 1 μs. Current density in the switch is approximately 25 kA/cm$^2$. The risetime of this current pulse can be varied by a factor of two by triggering the switch at different times (closing voltages). Switch design, operation, timing jitter characteristics and multiple shot use will be discussed.


## Introduction

Inductive storage pulsed power devices that use successive stages of opening switches to achieve pulse compression often require closing switches for isolation between stages. Pawn[1-4] is such a device. It uses two stages of power conditioning with an isolating switch between them. The equivalent circuit diagram for Pawn (Fig. 1) shows the 1 MJ, 44 kV capacitor bank and total series resistance ($R_T$). The bank is discharged through four railgap switches (RGS) into the first stage, consisting of a coaxial vacuum inductance in series with the bank inductance ($L_S$+$L_B$) and a copper wire fuse array opening switch (inductance $L_F$ and resistance $R_F$). The fuse heats and vaporizes, becoming resistive after about 15 μs. The first stage output voltage is the voltage generated at the vacuum flashover switch (VFS) by the fuse opening. $V_{VFS}$ is obtained by correcting the measured fuse voltage ($V_F$) for the inductive drop in the fuses. The VFS remains open during fuse conduction and is closed by external command just before $V_{VFS}$ begins to rise. This switches current into the second stage on a 1 μs time scale. Two types of vacuum opening switches have been used in the second stage on Pawn; a plasma erosion opening switch (PEOS)[4,5] and a plasma flow switch (PFS)[2,6]. The PEOS, illustrated in figure 2, conducts for about 1 μs and then opens in approximately 100 ns, delivering current to either a short circuit or an electron beam diode load ($L_L$ and $R_L$).

## VFS Design

As Pawn's second stage and load operate in vacuum, it is desirable for the first stage and the interstage closing switch to be under vacuum also. This eliminates the need for a high voltage vacuum interface. Inductance is reduced as well, due to the simpler geometry.

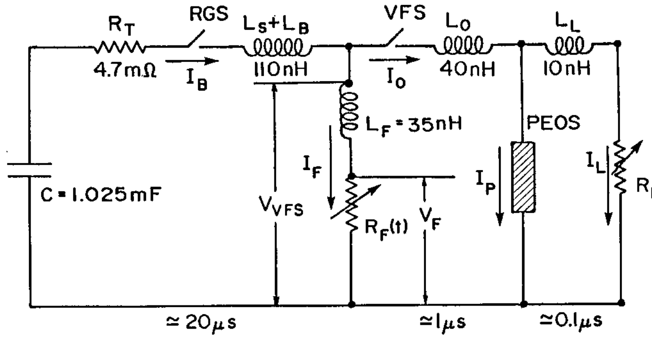


Figure 1. Pawn generator equivalent circuit.

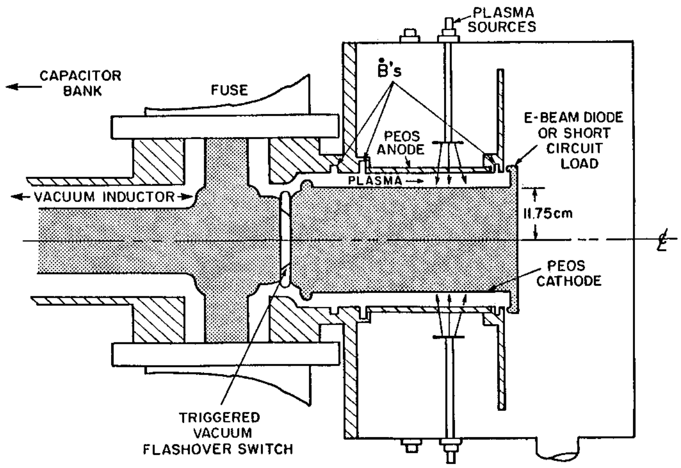


Figure 2. Pawn fuse stage, VFS and PEOS hardware.

The VFS is designed to remain open during the initial voltage transients associated with the RGS closure and for approximately 15 μs while the fuse conducts. It then closes on command when $V_{VFS}$ is between 25 and 50 kV, optimum switch out voltage for the fuse. Command triggering is required to achieve proper timing of the VFS with the firing of the plasma sources in the PEOS, and to determine the feasibility of synchronized operation of multiple capacitor banks into a common second stage in future designs. Low jitter in VFS closing and good reproducibility of operation are paramount.

The VFS consists of a polyurethane insulator ring sandwiched between metal electrodes (see Fig. 3). An insulating center bolt holds the assembly together. Numerous pumpout holes in the electrodes ensure that gases are not trapped within the switch. Inside the cathode, eight small spark sources produce plasma and ultraviolet (UV) light to initiate a flashover of the inner surface of the insulator. The discharge is confined to the interior of the VFS.

## Trigger System

The spark sources inside the VFS are powered by a 0.5 μf, 5 kv capacitor coupled to a ferrite core, 1:1 transformer (see Fig. 4). Each of the transformer's eight secondaries supplies a single spark

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14. ABSTRACT
**Pawn is a prototype inductive storage pulsed power generator with two switching stages. The first stage is a wire fuse array driven by a low voltage (=40 kV) capacitor bank, and the second stage is a fast opening vacuum switch such as a plasma erosion opening switch. A triggered vacuum flashover switch isolates the fuse stage from the second stage during fuse conduction. The switch consists of an insulating ring sandwiched between electrodes. Ultraviolet light and plasma from small spark discharges initiate a flashover of the insulator surface to close the switch. The trigger command is sent by fiber optic link.**

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source. The spark sources and the transformer are the only components of the trigger system that are in vacuum; the rest of the trigger package is housed inside the hollow center conductor of one of Pawn's fuse assemblies, in air. Thus, the battery operated unit floats at the fuse voltage, $V_F$. A fiber optic link is used to bring the firing command into the floating electronics package.

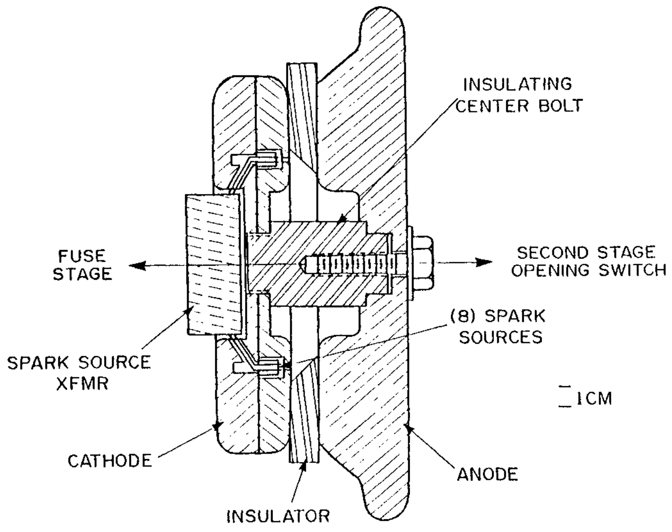


Figure 3. Pawn vacuum flashover switch.

The 5 kV pulse generator uses high speed, low jitter components to discharge the output capacitor. The timing jitter of the trigger electronics system is ±10 ns; this represents the timing uncertainty between initiation of the fiber optic command and the start of current rise in the spark source transformer.

Locating the trigger electronics inside the fuse center conductor provides excellent shielding against noise pickup, but space is very limited. The entire trigger pack, including batteries, fits into a space 5.7 cm in diameter by 45 cm long. The battery pack is mounted outboard of the 5 kv pulse generator. It can be removed to change the batteries without disturbing the rest of the trigger system. The power switch and regulated voltage test points are accessible even when the fuse package is sealed up for a shot. Reliability is increased by minimizing the need to remove and handle the somewhat delicate electronics package.

## VFS Operation

On Pawn, the VFS has a normal operating range of 15-60 kV (see Fig. 5), and a maximum holdoff voltage of 85 kV. It can conduct currents greater than 1 MA. The fuse stage output current carried by the VFS typically has a 1 μs risetime followed by a 20-25 μs decay; total charge carried is ≈25 coulombs per shot. Maximum voltage between the VFS assembly and the outer conductor is ≈200 kV, and the inductance of the VFS is ≈30 nH. Current density over the active area of the electrodes is ≈25 kA/cm$^2$.

The triggering characteristics of the most recent VFS configuration are illustrated in figure 6. The average time delay between the spark sources firing and actual VFS closure (see Fig. 6) varies with voltage by approximately 100 ns between 15 kv and 60 kv (as determined by a least squares fit to the data). Jitter at a given voltage is ±50 ns; this does not include switch prefires, in which the VFS self-closes. Three such prefires are shown in figure 6. Out of 52 shots fired, only three switching failures (not plotted) were attributable to VFS system faults. VFS failures caused by faults in other Pawn systems or by operator error are omitted.

As indicated by figure 6, there is a delay of 150-250 ns between the firing of the spark sources and closure of the VFS. This suggests that it is plasma emitted by the spark sources that initiates the flashover of the insulator surface, rather than ultraviolet light. A nearly instantaneous closure would be expected if flashover were caused by the UV.

Perfecting the externally triggered VFS has had an unforseen benefit in Pawn's role as a testbed for 1 μs conduction opening switches such as the PEOS. The operation of the fuse stage remains

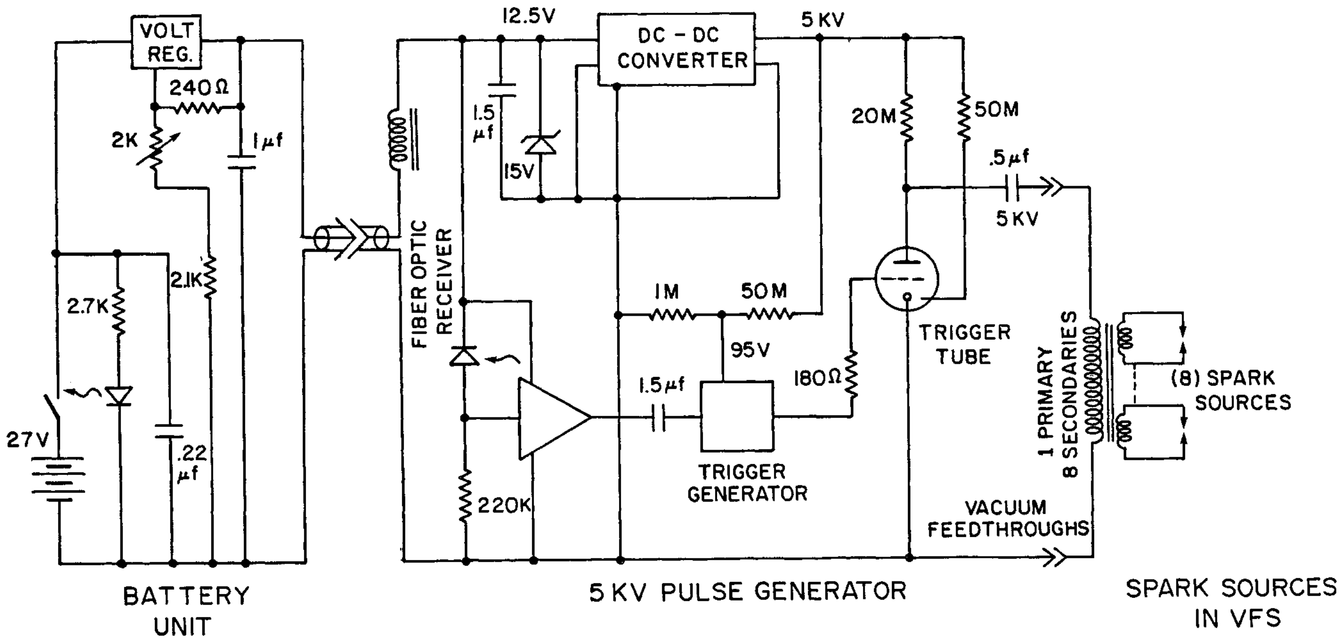


Figure 4. Schematic of VFS floating trigger system.

consistent when the VFS is closed anywhere within its maximum operating range of 15-85 kV; full output current and voltage are produced. However, the average rate of rise of the current into the second stage varies by as much as a factor of two depending on when (and hence at what voltage) the VFS is triggered (see Fig. 7). This makes it possible to study conduction times to the same current level of 0.7-1.4 μs.

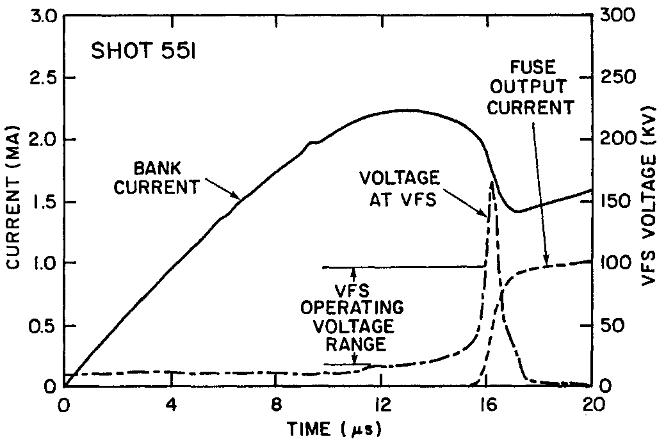


Figure 5. Pawn fuse stage operation, with VFS operating voltage range.

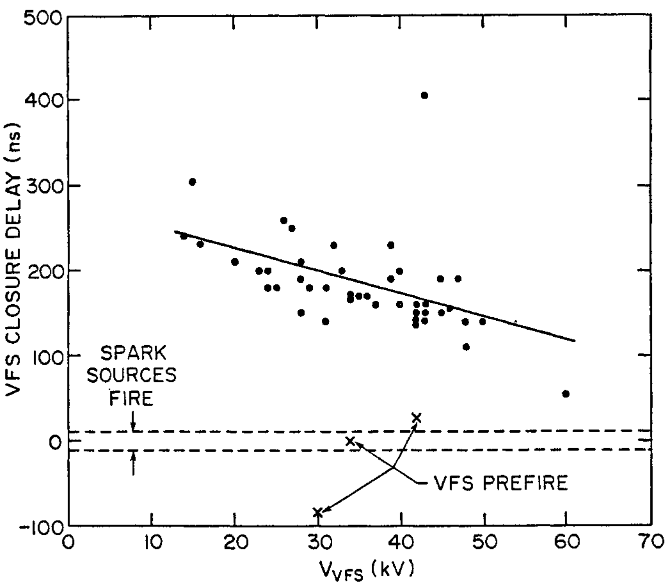


Figure 6. VFS closure delay time as a function of voltage, for operation with the final VFS configuration.

## Conclusion

The present Pawn vacuum flashover switch has been operational since July of 1988. Its performance is significantly better than earlier versions used on Pawn; a timing jitter of only ±50 ns and a greatly reduced number of prefires and switch breakdowns. Pawn's shot rate has been improved and it has become more versatile in its mission as an opening switch testbed.

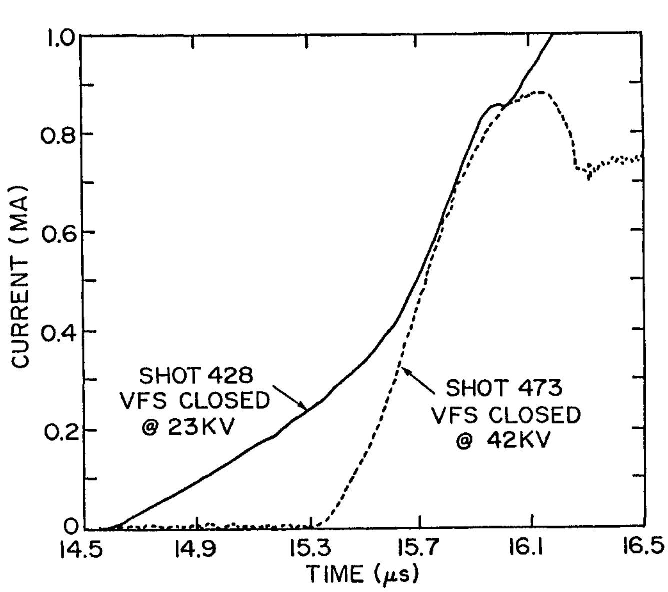


Figure 7. Control of fuse stage output current with triggered VFS.

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